

Assimilation of Satellite Color Observations
in a Coupled Ocean GCM-Ecosystem Model

Award # NAGW-3137

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Progress Report, 10/15/92

Hq. GRANT
IN-48-CR
129307
P.5

We have assimilated monthly average CZCS estimates of chlorophyll concentration into an ocean GCM containing a simple model of the pelagic ecosystem. (See the attached manuscript by Sarmiento et al. for details of this coupled system.) The assimilation was performed in the simplest possible manner, to allow us to assess whether there were major problems with the ecosystem model or with the assimilation procedure. We found that the current ecosystem model performed well in some regions, but failed in others to assimilate chlorophyll estimates without disrupting important ecosystem properties. This experiment gave insight into those properties of the ecosystem model that must be changed to allow data assimilation to be generally successful, while raising other important issues about the assimilation procedure.

For purposes of this experiment, model predictions of phytoplankton nitrogen concentrations in the top box of the GCM (0-10 m depth) were converted to chlorophyll concentrations using a nominal ratio of 1.59 mg chl a per mmol N, which corresponds to a chl:C ratio of 50 and a C:N ratio of 6.625 (Sarmiento et al. ms.). Daily estimates of CZCS chlorophyll P_{sat} were generated by linear interpolation between monthly means, and model chlorophyll (nitrogen) values P_{model} in the top box were forced towards the satellite values using the relationship

$$P_{model}(new) = P_{model}(original) + \gamma \Delta t (P_{sat} - P_{model}(original)) .$$

The parameter γ defines the rate at which the model is forced towards the data, so that $\gamma \Delta t$ is the fraction by which chlorophyll will be forced towards the satellite values per time step Δt (=1 hr in the current model). Values of γ of $5 d^{-1}$ and $0.2 d^{-1}$ were used in this experiment.

The color figure (Figure 1) allows comparison of satellite data (Figure 1a) to three separate model experiments. Figure 1b (case A3.1) shows model results without data assimilation. The general impression is that without data assimilation, yearly average chlorophyll levels are too high in the Equatorial region and too low at high latitudes. Forcing at $5 d^{-1}$ (case G3.1.8; Figure 3c) appears to make a substantial improvement over most of the ocean, while making predictions substantially worse at high latitudes. The less vigorous forcing of $0.2 d^{-1}$ (case G3.1; Figure 3d) makes more modest improvements over most of the ocean, but still makes predictions substantially worse at high latitudes.

(NASA-CR-191218) ASSIMILATION OF
SATELLITE COLOR OBSERVATIONS IN A
COUPLED OCEAN GCM-ECOSYSTEM MODEL
Progress Report (Princeton Univ.)

5 p

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N93-13714

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These results point to significant differences in the ability of the model to assimilate data under different circumstances. In areas where the model overpredicts phytoplankton density (the Equatorial region) and in areas where phytoplankton density is too low to support zooplankton (the subtropical gyre), the model seems to perform well if forced hard enough (Figure 1c). However, where the model underpredicts phytoplankton densities, it performs poorly, indicating the need to improve the model's performance under these circumstances.

Plots of ecosystem properties (Figure 2) at the location of OWS India (59N, 19W) give insight into why the model performs so poorly when the assimilation procedure tries to increase phytoplankton densities. When the model is near steady state and zooplankton are present (conditions that obtain over the whole year in the Equatorial zone and in Summer and Fall in high latitudes), zooplankton grazing constrains phytoplankton densities to the narrow band 0.25 to 0.342 mmol N m^{-3} (0.4 to 0.55 mg chl m^{-3}). (See p. 33 of the Sarmiento et al. ms.) If satellite chlorophyll estimates are above this range, as they are at OWS India, forcing the model predictions towards the satellite values cause zooplankton densities to increase to the point where they are able to eat all the added chlorophyll, cancelling out the assimilation procedure almost completely and returning phytoplankton densities to their steady-state range. This additional consumption by zooplankton results in additional ammonium production. Then, since the phytoplankton are constrained to a small population size by zooplankton grazing, they cannot consume all the additional ammonium, allowing ammonium to build up to unrealistic levels. Finally, because ammonium inhibits the uptake of nitrate, nitrate goes unused during the growing season, again an unrealistic result for this location. (These results should be compared to the run without data assimilation [Figure 3], which we consider to be a reasonable approximation to the real situation.)

A central problem that must therefore be addressed in the next year is to restructure the ecosystem model in such a way that model phytoplankton densities are not constrained by zooplankton grazing to a narrow range of values. One way to relieve this problem would be to introduce density-dependent death into the zooplankton equation (J. Steele, pers. comm.). This approach will work only within a limited range, however, so that ultimately the single phytoplankton-zooplankton food chain of the present model will need to be replaced by a more complex structure, so that if one phytoplankton species reaches its limit, others will be present to assimilate the additional chlorophyll. We are actively pursuing both avenues at the present time.

In addition, other details of the assimilation procedure must also be addressed. First, we must be able to model more precisely the relationship between satellite chlorophyll and model nitrogen, noting particularly the effects of illumination and nitrogen nutrition on C:N and chl:C ratios. Second, we must explore various forcing time scales, to try to define a "natural" time scale for data assimilation into an ecosystem model. Finally, we must determine whether the present data assimilation procedure, where the model is forced towards observations only in the top box, produces results that differ significantly from those produced by using other protocols, such as adjusting the chlorophyll levels at all depths simultaneously.

Chlorophyll in mg-Chl/m³; Annual mean, Depth=5 m:

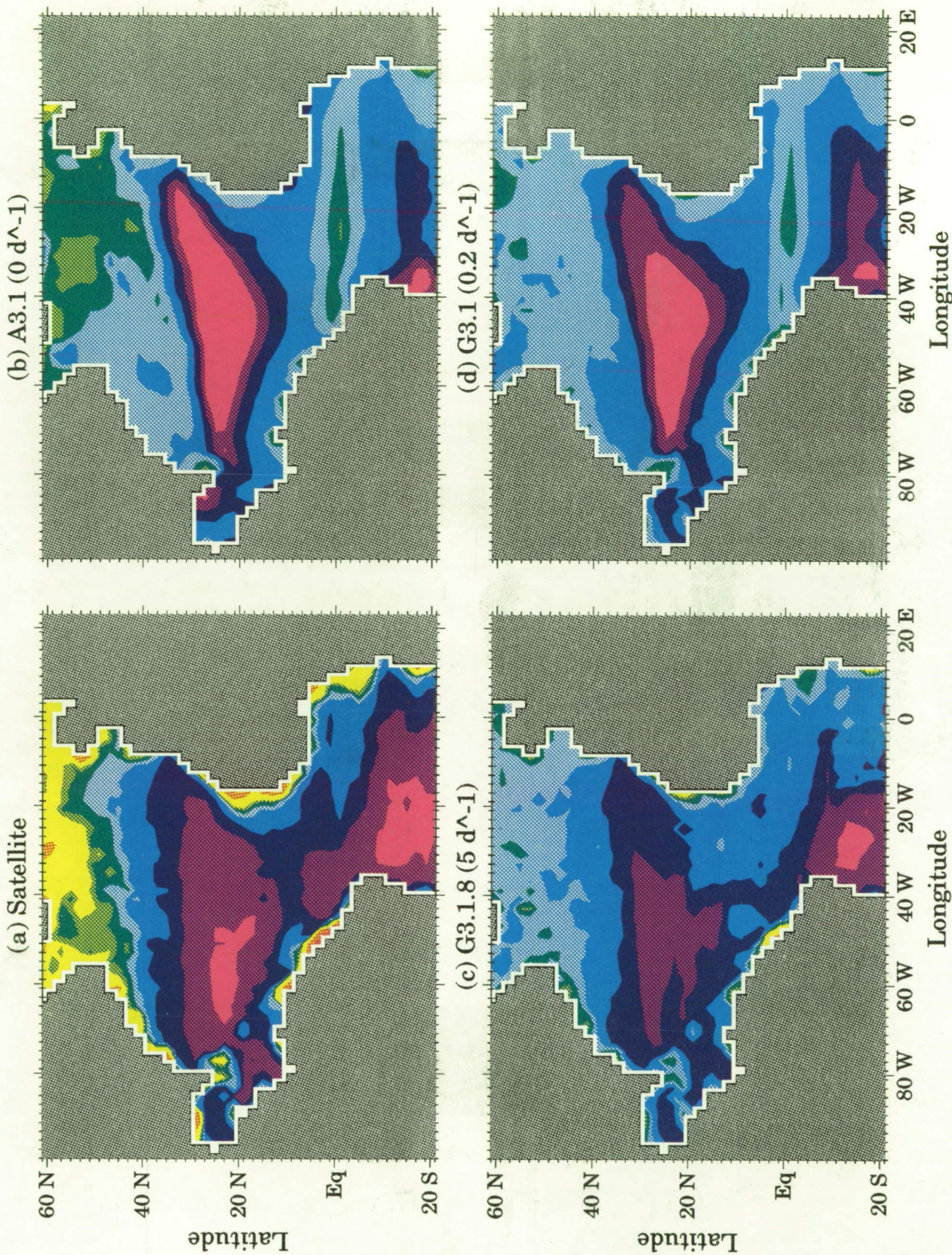


Figure 1

Natl2h, year 1900; Nitrate ecosystem, G3.1.8, Year 3; Station plot at (59 N, 19 W)

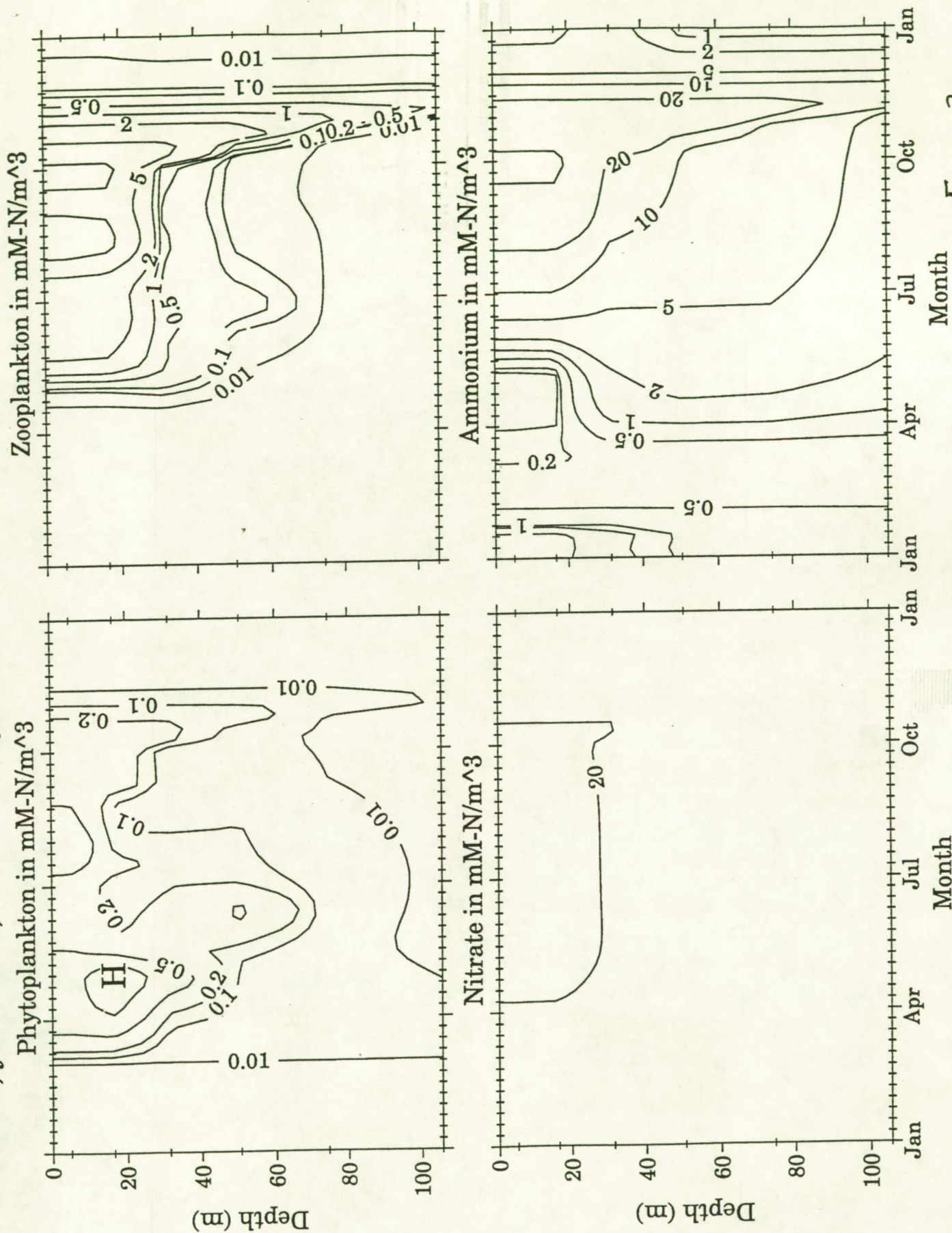


Figure 2

Natl2h, year 1900; Nitrate ecosystem, A3.1, Year 3; Station plot at (59 N, 19 W)

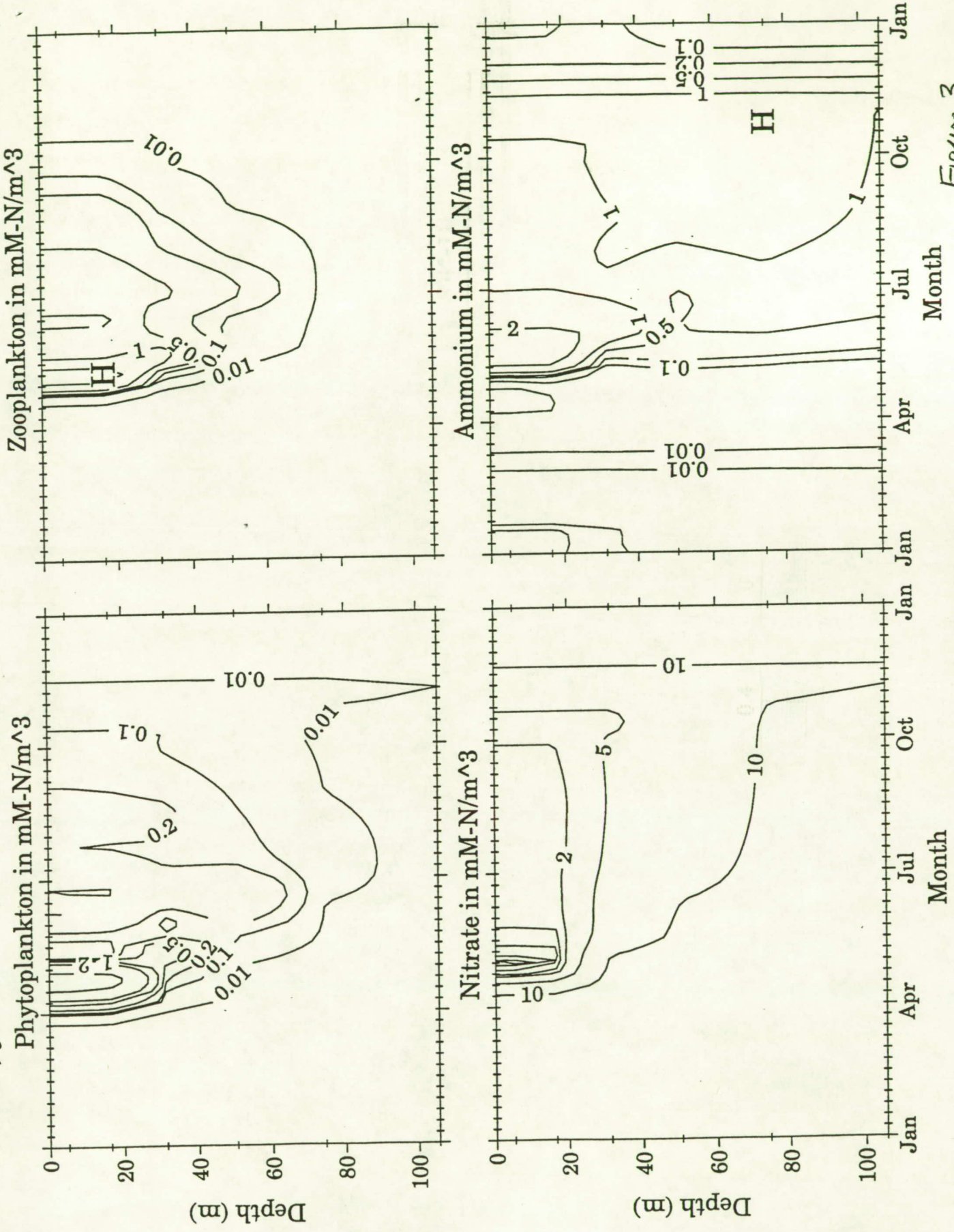


Figure 3

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